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Radian Corp., Research Triangle Park, NC

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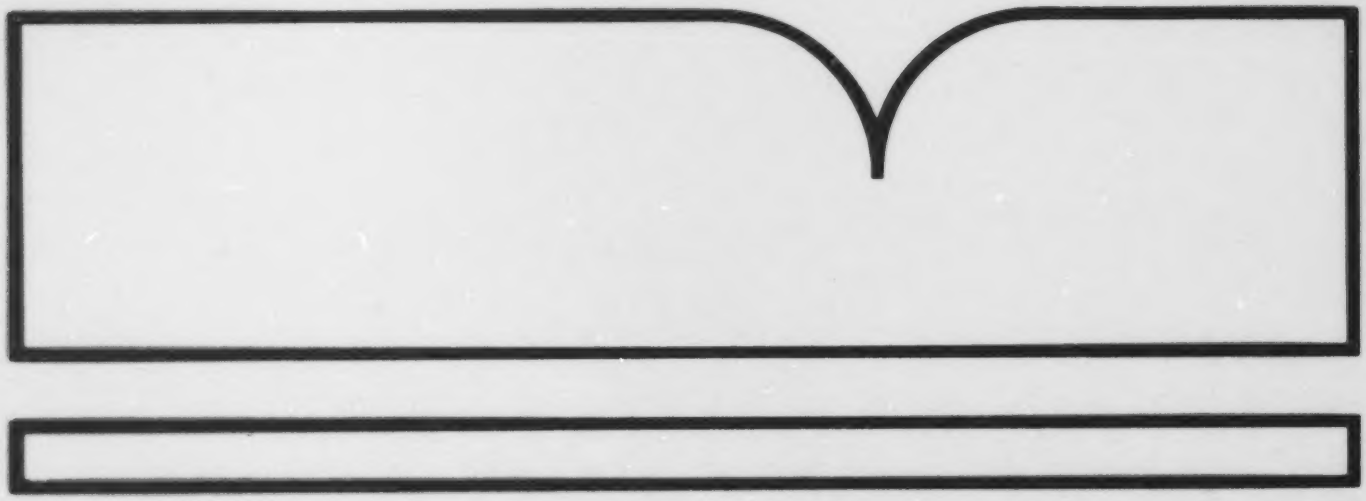

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INDUSTRIAL BOILER FURNACE SORBENT INJECTION ALGORITHM DEVELOPMENT

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ABSTRACT

The Industrial Combustion Emissions (ICE) Model is one of four stationary source emission and control cost forecasting models developed by the Air and Energy Engineering Research Laboratory for the National Acid Precipitation Assessment Program. The ICE Model projects air pollution emissions (sulfur dioxide, sulfates, nitrogen oxides and particulate matter), cost and fuel mix for industrial fossil fuel-fired (natural gas, distillate and residual fuel oil and coal) boilers by state and year (1980 baseline, 1985, 1990, 1995, 2000, 2010, 2020, and 2030).

This document describes the development of a performance and control cost algorithm for the ICE Model. This algorithm enables the ICE Model to consider, on an economic basis, the use of hydrated lime injection for sulfur dioxide control when a SO_2 emission reduction strategy is implemented. The algorithms described in this report have been incorporated into ICE Model Version 6.0.

CONTENTS

Abstract iii
Figures vi
Tables. vi

1. Introduction 1
2. Design Bases 3
   - Process Description 3
   - Sorbent Storage and Handling 3
   - Boiler Modifications 5
   - Particulate Matter Control 7
3. Cost Development 9
   - Furnace Sorbent Injection System 9
   - Capital Costs 9
   - Operating and Maintenance Costs 11
   - Particulate Matter Control Costs. 11
   - Capital Costs 13
   - Operating and Maintenance Costs... 18
4. Costing Methodology 22
   - Capital Costs 22
   - Operating and Maintenance (O&M) Costs 22
   - Annualized Costs 25
5. Case Studies 28

References 32
Appendices

A. Furnace Lime Injection Costs for New Industrial Boilers 34
B. Furnace Lime Injection Costs for Retrofit Boilers firing 250 million BTU/hr or more 38
C. Furnace Lime Injection Costs for Retrofit Boilers firing less than 250 million BTU/hr. 42

FIGURES

Figure		Page
2-1	Furnace Sorbent Injection System	4
2-2	Hydrated Lime Performance Curve	6

TABLES

Table		Page
3-1	Operating and Maintenance Costs For The Furnace Sorbent Injection System	12
3-2	Sorbent Injection Particulate Matter Control Capital Costs For New Boilers	14
3-3	Nomenclature Used in Cost Algorithms	15
3-4	Particulate Matter Loading of Coal Flyash and Lime Injection	17
3-5	Sorbent Injection Particulate Matter Control Capital Cost for Retrofit Boilers	19
3-6	Sorbent Injection Particulate Matter O&M Costs for New Boilers	20
3-7	Sorbent Injection PM O&M Costs for Retrofit Boilers	21
4-1	Capital Cost Components	23
4-2	Operating and Maintenance Cost Components	24
4-3	Unit Cost Rates Recommended for Use in Calculations . .	26
4-4	Annualized Cost Components	27
5-1	Economic Premises for Case Study	29
5-2	Furnace Sorbent Injection Costs for New Boilers	30
5-3	Furnace Sorbent Injection Costs for Retrofit Boilers . .	31

SECTION 1

INTRODUCTION

This report documents the development of the furnace sorbent (hydrated lime) injection cost algorithm for coal-fired industrial boilers. This document describes the methods used to develop capital, operating, and annualized costs for industrial size boilers. The boiler size range examined covers units with capacities from 100 million Btu per hour input to 1300 million Btu per hour. All costs presented in this report are in June 1985 dollars.

The cost algorithm is incorporated within the Industrial Combustion Emission (ICE) Model, Version 6.0 developed by the Environmental Protection Agency for the National Acid Precipitation Assessment Program (NAPAP). The furnace sorbent injection technology is one of several technologies being developed specifically for application at existing uncontrolled electric utility and industrial boilers. The cost algorithm developed is based on results from bench and pilot testing conducted through 1985. The algorithms presented here do not include the results of more recent research into the use of humidification. The use of humidification may reduce overall system costs (i.e., the costs of sorbent injection plus particulate matter control) below those contained in this report if the use of humidification avoids retrofit of additional particulate matter (PM) control system capacity. This reduction in PM control costs would more than offset increases in the sorbent injection system costs due to addition of a humidification system.

Because the algorithms in this report are not based on humidification, retrofitted units likely to have low efficiency electrostatic precipitators (ESPs) are assumed to completely abandon the existing ESPs and install a fabric filter (FF) system concurrently with installation of the hydrated lime sorbent injection system. All existing units less than 250 million Btu/hour heat input are assumed to be in this category. Larger existing units are assumed to have upgradable ESPs.

Section 2 presents the design bases for estimating sorbent injection costs. Section 3 describes the algorithm development and Section 4

presents the costing methodologies used in calculating the capital, operating and annualized costs. Section 5 presents several case study results for furnace sorbent injection. Appendices A through C present the listing of the algorithms as entered into the Lotus spreadsheets.

SECTION 2

DESIGN BASES

This section presents the major assumptions and rationale used in developing the furnace injection system model. Section 2.1 presents a description of the process and a flow diagram. The furnace injection system can be broken down into three major components. The reagent storage and handling system is discussed in Section 2.2. The necessary boiler modifications are presented in Section 2.3. Finally, the impacts of furnace injection on particulate matter control are discussed in Section 2.4. The cost assumptions and bases are discussed in detail in Sections 3 and 4.

2.1 PROCESS DESCRIPTION

A generalized flow diagram of the furnace sorbent injection process is shown in Figure 2-1. The furnace injection scheme involves pneumatic injection of the sorbent into the flue gas (in the upper furnace) with subsequent particulate collection downstream. The injected sorbent reacts with the SO_2 in the flue gas to form solid products. The reaction product and the unreacted sorbent are then collected downstream with the fly ash in a baghouse or electrostatic precipitator.

For this cost analysis, hydrated lime is selected as the sorbent. By purchasing hydrated lime, the industrial boiler operator eliminates the need for limestone pulverizers, crushers and bulky storage piles. Also lime has exhibited higher SO_2 capture than limestone.

2.2 SORBENT STORAGE AND HANDLING

The design bases for the furnace injection sorbent storage and handling system are as follows:

- The sorbent storage silo contains a seven-day supply.

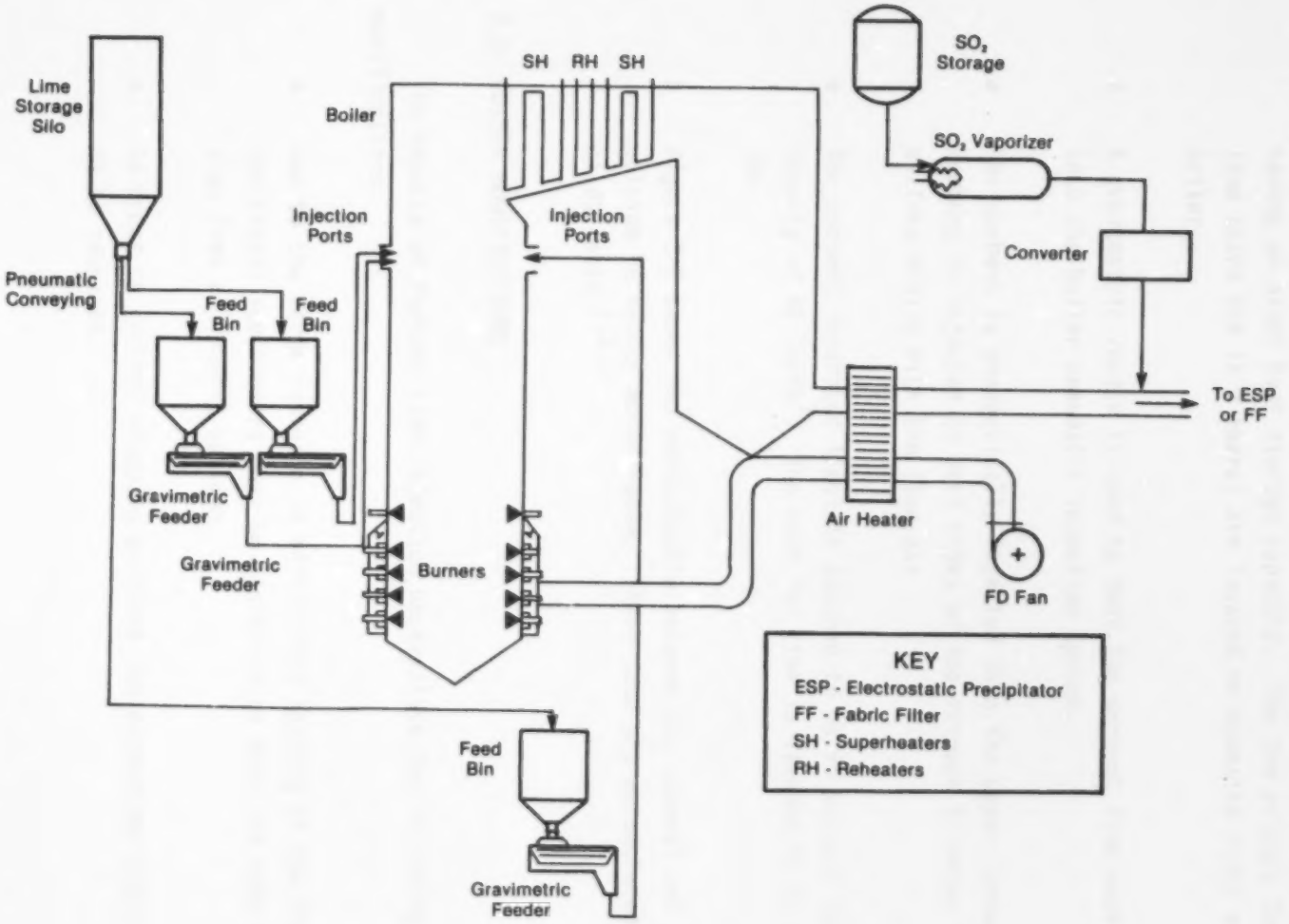

Figure 2-1. Furnace Sorbent Injection System

- The sorbent is pneumatically conveyed into three feed bins, each having an eight hour storage capacity. The two primary feed bins (the third bin is a spare) are located on opposite sides of the boiler.

- A gravimetric feeder is used to feed the sorbent from each feed bin into the boiler pneumatic injection system.

- The sorbent is pneumatically injected into the upper furnace. The sorbent is injected on both sides of the furnace in order to provide uniform mixing with the flue gas.

- The sorbent (hydrated lime) is assumed to be 95 percent CaO with a density of 40 lb/ft^3. The cost for lime is assumed to be $75 per ton.

- Figure 2-2 shows the relationship between SO_2 removal and the calcium to sulfur moler ratio. These data are accumulated from pilot tests.[1,2,3]

2.3 BOILER MODIFICATIONS

The impacts of furnace lime injection necessitate the following boiler modifications:

- Due to the large increase in particulate loading of the flue gas, additional sootblowers must be installed to keep the heat transfer area free of deposit buildup.

- In order to control plugging problems the economizer tubes will need to be respaced.

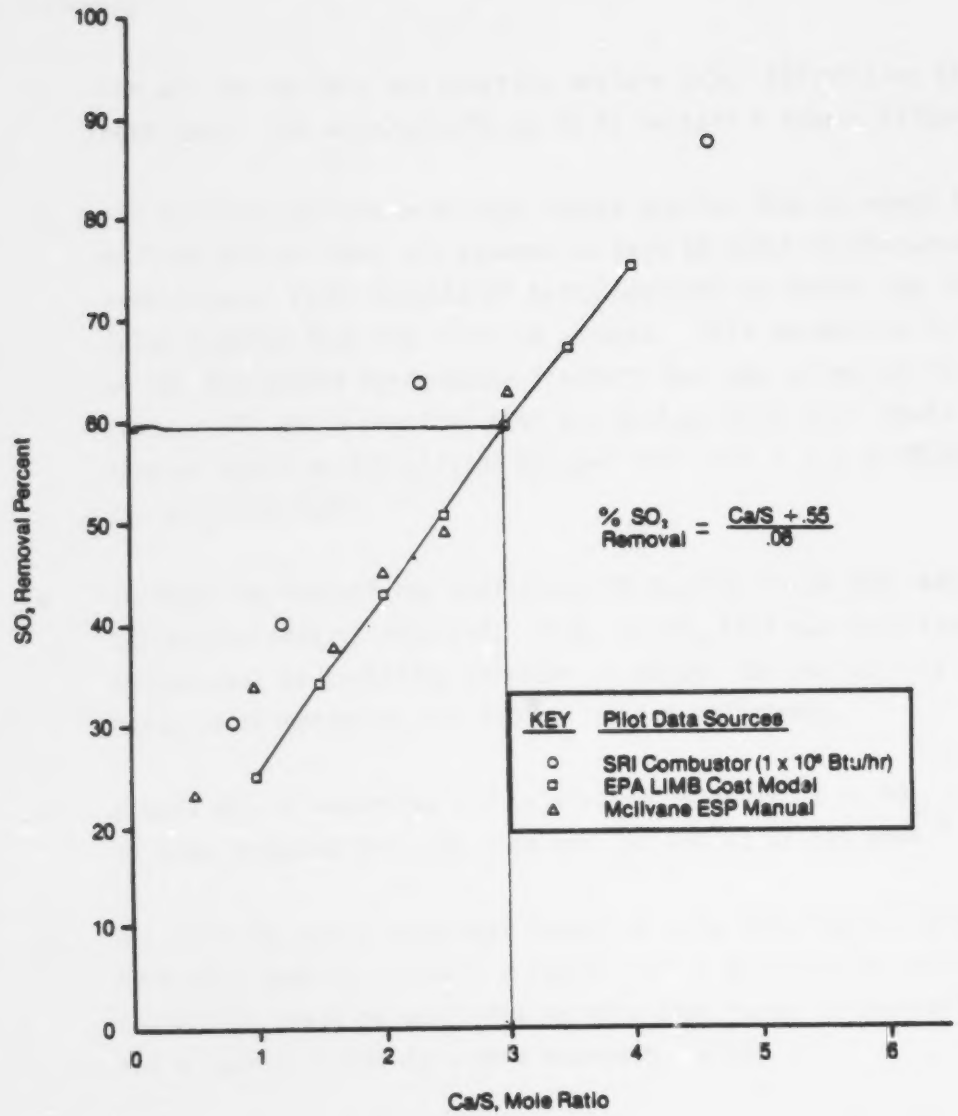

Figure 2-2. Hydrated Lime Performance Curve.

2.4 PARTICULATE MATTER CONTROL

Furnace sorbent injection alters the quantity and chemical characteristics of particulate matter emitted from the boiler. This results in modifications of the particulate matter control system, which are based on the following:

- For all new boilers and existing boilers under 250 million Btu/hour heat input, the economic choice is to install a fabric filter.

- All existing boilers with heat inputs greater than or equal to 250 million Btu per hour are assumed to have an existing electrostatic precipitator (ESP) capable of being upgraded to handle the increased inlet loading from the injected sorbent. This assumption is based on the New Source Performance Standard that was effective in 1971 (Subpart D) which requires that all boilers with heat inputs greater than or equal to 250 million Btu per hour meet a 0.1 lb PM/million Btu emission limit.

- In order to control the additional PM loading in an ESP, additional collection area is required. Also, an SO_3 flue gas conditioning system must be installed in order to adjust the resistivity into a range which optimizes the ESP collection efficiency.

- Liquid SO_2 is vaporized and catalytically oxidized to SO_3. The SO_3 is then injected into the flue gas (at $350^{o}F$) at 100 ppmv.[4]

- All existing units with heat inputs of less than 250 million Btu per hour will need to retrofit a fabric filter because the specific collection areas on most ESPs in this size range is typically low and a fabric filter is a more economic choice.

- It is assumed that all units employing fabric filters as the particulate matter control device will incur a sorbent savings of 10 percent due to the additional SO_2 removal across the bag filters.

- Due to the sorbent savings, all new units will install fabric filters as the PM control device.

SECTION 3

COST DEVELOPMENT

This section presents the procedures and data sources used to develop a cost algorithm for the furnace sorbent injection system. Section 3.1 discusses the furnace sorbent injection costs. Section 3.2 discusses the downstream particulate matter control costs.

3.1 FURNACE SORBENT INJECTION SYSTEM

3.1.1 Capital Costs

The costs of the sorbent injection system are based on data gathered from manufacturers and literature sources. The major capital cost components include the storage silo, feed bins, gravimetric feeders, and pneumatic conveyors. Most of the capital costs are dependent on the sorbent feed rate into the boiler. The following equation defines the sorbent mass feed rate.

$$\text{Sorbent Feed Rate (lb/hr)} = \frac{24{,}266\ (Q)\ (\%S)\ (Ca/S)}{H}$$

where Q= heat input (10^6 Btu/hr)
%S = coal sulfur content (%)
Ca/S = calcium to sulfur molar ratio
H = heat content (Btu/lb)

The sorbent storage silo cost is based on information from the Richardson Rapid System and one manufacturer.[5] The storage silos are assumed to have a seven day storage capacity. The costs of the covered storage silo is dependent on the sorbent feed rate. A logarithmic plot of equipment cost versus lime feed rate yielded the following equation:

$$\text{Storage Silo (\$)} = 53.4\ (\text{sorbent feed rate})^{0.82}$$

The feed bin costs are based on information from two manufacturers. As with the storage silo costs, the feed bin costs are dependant on the sorbent

feed rate. Also, there are three feed bins included in this injection system. Two of the bins will be located on opposite sides of the boiler (to ensure uniform mixing) and the third bin is a spare. Each bin has an eight hour sorbent storage capacity. A logarithmic plot of the cost data and lime feed rate yielded the following equation:

$$\text{Feed Bins (\$)} = 88.5\ (\text{sorbent feed rate})^{0.6145}$$

The gravimetric feeder costs are based on data from the Richardson Rapid System.[6] The injection system incorporates 3 gravimetric feeders, one for each feed bin. A straight line plot of cost versus sorbent feed rate yielded the following equation:

$$\text{Gravimetric Feeders (\$)} = 0.2889\ (\text{sorbent feed rate}) + 9293$$

Cost data for the pneumatic conveying systems was gathered from two manufacturers. There are a total of six pneumatic conveying systems needed for the lime injection system (three lead from storage silos to feed bins, three lead from feed bins to boiler injection ports). Due to the lack of other available information, the injection port costs are assumed to be 25 percent of the pneumatic costs. A semi-logarithmic plot of cost versus lime feed rate yielded the following equations:

$$\text{Pneumatic Conveyor costs (\$)} = 9614 \exp\left[2.21 \times 10^{-5}\ (\text{sorbent feed rate})\right]$$

$$\text{Injection Ports (\$)} = 0.25\left[9614 \exp\left(2.21 \times 10^{-5}\ (\text{sorbent feed rate})\right)\right]$$

The economizer modification and sootblower costs are based on information from the utility furnace sorbent injection algorithm.[7] The costs cited for these items in the utility algorithm are reported as installed costs. For the industrial boiler algorithm, equipment and installation costs are reported separately. An installation cost of 30 percent was assumed for the sootblower and economizer modifications. Once the cost of installation is removed the following equipment costs result:

Sootblowers = 73 [heat input (10^6 Btu/hr)]

Economizer Modification = 254 [heat input (10^6 Btu/hr)]

In the case of retrofit, an additional 30 percent is included in the costs described above.

3.1.2 Operating and Maintenance Costs

The direct operating labor required for the sorbent injection system includes eight hours to fill the storage silo once each week and 42 hours per week to fill the feed bins once each shift (two hours per shift). Supervisory labor is assumed to be 15 percent of the total direct labor cost. Similarly, maintenance labor is assumed to be 25 percent of the total direct labor cost.[8] The spare parts required are minimal and are assumed to be two percent of the total direct and indirect capital cost of the sorbent injection system.

The raw material and utility costs are a function of the sorbent feed rate into the furnace. Electricity is needed to operate the six pneumatic systems. The raw material cost is the sorbent cost. It is assumed that all of the sorbent and reaction products are entrained in the flue gas. Thus, additional solid waste disposal in the boiler bottom ash system is not required. Table 3-1 presents the operating and maintenance cost equations developed for the sorbent injection system.

3.2 PARTICULATE MATTER CONTROL COSTS

Particulate matter control costs are based on a fabric filter for new boilers. This control device choice is based on the least cost option; it is less expensive to install and operate a fabric filter (assuming a 10% reagent savings). For existing units, it is assumed that an ESP is already in place for boilers firing 250 million Btu per hour or more (in accordance with New Source Performance Standards in Subpart D). For existing units smaller than 250 million Btu per hour, the economic choice is to install a fabric filter.

TABLE 3-1. OPERATING AND MAINTENANCE COSTS FOR THE FURNACE SORBENT INJECTION SYSTEM ($/YR)

Direct Labor = 2600 (Direct labor rate) (Labor factor)

Supervision = 390 (Supervision labor rate)

Maintenance = 650 (Maintenance labor rate)

Spare Parts = 0.02 (Total Direct and Indirect capital cost of sorbent injection system)

Electricity = (52.56 (Sorbent feed rate) + 251,850)*(Electricity Rate)* (Capacity Factor)

Sorbent = 4.38 (Sorbent feed rate) (Sorbent rate) (Capacity Factor)

$$\text{Sorbent Feed Rate (lb/hr)} = \frac{24{,}260\ (\text{Heat Input } (10^6 \text{ Btu/hr}))\ (\%\text{Sulfur})\ (\text{Ca/S})}{\text{Heating value (Btu/lb)}}$$

3.2.1 Capital Costs

The capital cost equations for fabric filters and electrostatic precipitators are based on algorithms developed for industrial boilers.[8] These cost equations were developed as part of the Industrial Boiler New Source Performance Standard development program. For fabric filters, the capital costs are dependent on the flue gas flow rate. Since sorbent injection has little effect on the flue gas flow rate, the capital costs are unaffected. The increased PM loading due to sorbent injection does not affect the fabric filter capital cost. Table 3-2 summarizes the total sorbent injection PM control costs for new boilers. Table 3-3 presents a table of nomenclature used in the cost algorithms. The injection of sorbent into the flue gas stream, causes a large increase in the particulate matter loading. The total collection plate area needed in the ESP depends upon the PM loading of the flue gas. The additional collection area needed is calculated based on the percent increase in PM loading due to sorbent injection.

The particulate matter loading for coal fired boilers is calculated using the AP42 factors for spreader stoker and pulverized coal boilers.[9] The PM loading due to sorbent injection is dependent on the SO_2 removal efficiency, the Ca/S moler ratio, and the sulfur and heat content of the coal. Table 3-4 presents the equations needed to calculate PM loading before and after sorbent injection.

Sorbent injection also increases the resistivity of particulate matter in the flue gas to levels which significantly reduce ESP collection efficiency. For this reason, an SO_3 conditioning system is installed to reduce particulate matter resistivity to an acceptable level. Capital costs for the SO_3 conditioning system are based on data from literature and information from one manufacturer.*,[10] A logarithmic plot of the cost data versus boiler heat input capacity yielded the following equation:

$$SO_3 \text{ Conditioning} = 166{,}856 \text{ heat input } (10^6 \text{ Btu/hr})^{0.15}$$

---

*Telephone conversation between Johnson, K. L. (Radian) and Gil Rehm (Rift Engineering Co.), May 16, 1980.

TABLE 3-2. SORBENT INJECTION PARTICULATE MATTER CONTROL CAPITAL COSTS FOR NEW BOILERS (JUNE 1985 $)

Fabric Filter

PM Equipment = $12.36 (FLW)^{0.966}$

PM Installation = $-2,232,290 + 249,721 \ln (FLW)$

PM Indirects = $37.03 (FLW)^{0.821}$

Where,

for spreader stoker

$FLW = Exp (8.14 \times 10^{-5} H) * 1.66 \times 10^{6} Q/H$

for pulverizer

$FLW = Exp (8.03 \times 10^{-5} H) * 1.62 \times 10^{6} Q/H$

TABLE 3-3. NOMENCLATURE USED IN COST ALGORITHMS

Capital and O & M Costs

EQUIP = Equipment
INST = Installation
TD = Total Direct
TDI = Total Direct and Indirect
Cont = Contingency
TK = Turnkey
WC = Working Capital
TDOM = Total Direct Operating and Maintenance
OH = Overhead
DL = Direct Labor
Spvs = Supervision
Mant = Maintenance
SP = Spare Parts
LC = Lime Cost
SW = Solid Waste Disposal
ELEC = Electricity

Annualized Costs

CR = Capital Recovery
CRF = Capital Recovery Factor
Misc = Miscellaneous
WCC = Working Capital Cost (interest on WC)

Boiler Variables

Q = Heat Input (10^6 BTU/hr)
FLW = Flue Gas Flowrate (acfm)
CF = Capacity Factor

Fuel Specifications

H = Heating Values (Btu/lb)
S = Sulfur Content (%)
A = Ash Content (%)

PM Control Specifications

UncPM = Uncontrolled PM Emissions (lb/10^6 Btu)
CtrPM = Controlled PM Emissions (lb/10^6 Btu)
SCA = Specific Collection Area (ft^2/1000 acfm)
TPA = Total Plate Area (ft^2)
EffPM = PM Removal Efficiency (%)

(Continued)

TABLE 3-3. NOMENCLATURE USED IN COST ALGORITHMS (Continued)

Lime Specifications

Ca/S = Reagent Ratio (mol Ca/mol S)
LFR = Lime Feed Rate (lb/hr)

Cost Rates

DLR = Direct Labor Rate ($/man hr)
SLR = Supervision Labor Rate ($/man hr)
MLR = Maintenance Labor Rate ($/man hr)
ELR = Electricity Rate ($/Kwhr)
LR = Lime Rate ($/ton)
SWR = Solid Waste Rate ($/ton)
WTR = Water Rate ($/1000 gal)
SO_2R = Liquid SO_2 Rate ($/ton)

Miscellaneous

LF = Labor Factor
EFFSO2 = SO_2 Removal Efficiency (%)

TABLE 3-4. PARTICULATE MATTER LOADING OF COAL FLYASH AND LIME INJECTION

for Spreader Stoker Boiler

$$\text{Uncontrolled PM } (lb/10^6 \text{ Btu}) = \frac{30.000}{H}$$

for Pulverized Coal Boiler

$$\text{Uncontrolled PM } (lb/10^6 \text{ Btu}) = \frac{(5000)\ (\%\ A)}{H} \quad \text{for dry bottom boiler}$$

$$= \frac{(3500)\ (\%\ A)}{H} \quad \text{for wet bottom boiler}$$

for Lime Injection

$$\text{Additional PM} = \frac{250\ (\%S)\ (\%\ \text{Eff}\ SO_2) + 17{,}500\ (\%S)\ (Ca/S)}{H}$$

% Increase in PM loading due to Lime Injection

for Spreader Stoker Boiler

$$\%\ \text{Increase} = 0.0083\ (\%S)\ (\%\ \text{Eff}\ SO_2) + 0.5833\ (\%S)\ (Ca/S)$$

for Pulverized Coal Boiler

$$\text{Dry Bottom } \%\ \text{Increase} = \frac{0.05\ (\%S)\ (\%\ \text{Eff}\ SO_2) + 3.5\ (\%S)\ (Ca/S)}{\%A}$$

$$\text{Wet Bottom } \%\ \text{Increase} = \frac{0.0714\ (\%S)\ (\%\ \text{Eff}\ SO_2) + 5.00\ (\%S)\ (Ca/S)}{\%A}$$

where, $Ca/S = 0.06\ (\%\ \text{Eff}\ SO_2) - 0.55$

As previously discussed, for existing units with a heat input of 250 million Btu per hour or more, it is assumed an ESP is already in operation. Thus to retrofit a sorbent injection system to an existing ESP, additional collection area and an SO_3 conditioning system is required. The amount of additional plate area required is directly proportional to the increase in particulate matter loading due to sorbent injection. For existing boilers firing less than 250 million Btu per hour, a fabric filter system is required (least cost option). Also, an additional 30 percent is added to the capital cost to account for spatial problems that may be encountered when retrofitting an ESP or fabric filter. The capital costs for retrofit sorbent injection PM controls are summarized in Table 3-5.

3.2.2 Operating and Maintenance Costs

Table 3-6 presents the annual O&M costs for new fabric filters. A few modifications were made to reflect the additional PM loading when sorbent is injected into the flue gas stream. For fabric filters the spare parts (spare bags) cost is doubled in anticipation that the bags would need to be replaced more frequently. Also, a sorbent savings is incurred because SO_2 removal occurs on the bag surface. In this study we assume a 10% sorbent savings will occur.

For existing boilers, the PM control O&M costs for fabric filters are the same as the O&M costs for new boilers. However for ESPs, the O&M costs reflect only the additional cost due to sorbent injection. Since extra collection area is installed, the spare parts and electricity costs increase. Also, due to the increases in PM loading, the water and solid waste disposal costs increase. It is assumed that liquid SO_2 is vaporized and catalytically oxidized to SO_3, which is then injected into the flue gas ($350^{o}F$) at 100 ppmv. This is a conservative estimate of the SO_3 concentration necessary for lime injection applications.[4] Liquid SO_2 cost is a function of the flue gas flow rate. Table 3-7 presents the annual O&M costs for retrofit sorbent injection PM controls.

TABLE 3-5. SORBENT INJECTION PARTICULATE MATTER CONTROL CAPITAL COST FOR RETROFIT BOILERS (JUNE 1985$)

Fabric Filter (for units Q < 250)

Add 30% (for retrofit) to costs presented in Table 3-2.

Electrostatic Precipitator (for units Q > 250)

SO_3 Conditioning = $216{,}913\ (Q)^{.15}$

PM Equipment = $3475\ (\text{TPA add't})^{0.52}$

PM Installation = 1.10 (PMEQUIP)

PM Indirects = 0.334 (PMEQUIP + PMINST)

Specific Collection Area =

$$383\ S^{(-11.256\ EFFPM^{-0.745})}\ (100\text{-}EFFPM)^{(-0.366\ S^{-0.051})}$$

Total Additional Plate Area = $\frac{(SCA)\ (FLW)}{1000}$ (% Increase In PM Loading After Sorbent Injection)

TABLE 3-6. SORBENT INJECTION PARTICULATE MATTER O&M COSTS FOR NEW BOILERS

Fabric Filter

Direct Labor = (844 + 8.82 (Q)) (DLR) (LF)

Supervision = 0

Maintenance = $(1{,}014 + 0.007\ (Q)^2)$ (MLR) (LF)

Spare Parts = $0.864\ (FLW)^{0.997}$

Electricity = 47.8 (CF) (ELR) $(FLW)^{0.953}$

Solid Waste Disposal =

4.38 (CF) (Q) (SWR) (UncPM After Injection -CtrPM)

Lime Reagent Savings = (-0.438) (LFR) (CF) (LR)

where,

for Spreader Stoker

FLW = Exp $(8.14 \times 10^{-5} H)$ 1.66×10^6 Q/H

for Pulverizer

FLW = Exp $(8.03 \times 10^{-5} H)$ 1.62×10^6 Q/H

TABLE 3-7. SORBENT INJECTION PM O&M COSTS FOR RETROFIT BOILERS

Fabric Filter (For units Q < 250)

Same as presented in Table 3-6.

Electrostatic Precipitators (For units Q $\geq$ 250)

Spare Parts = 5.52×10^{-3} (PMEQUIP + PMINST + PMIND)

Electricity = 26.28 (CF) (TPA After Injection) (ELR)

Water = 28.03 (Q) (CF) (WTR) (UncPM Add't)

Liquid SO_2 = 2.48×10^{-3} (FLW) (CF) (SO_2 R)

Solid Waste Disposal = 4.38 (CF) (Q) (UncPM Add't)

where,

for Spreader Stoker

$$FLW = \text{Exp}\ (8.14 \times 10^{-5} H)\ 1.66 \times 10^{6}\ Q/H$$

for Pulverizer

$$FLW = \text{Exp}\ (8.03 \times 10^{-5} H)\ 1.62 \times 10^{6}\ Q/H$$

Specific Collection Area =

$$383\ S^{(-11.256\ EFFPM^{-0.745})}\ (100\text{-}EFFPM)^{(-0.366\ S^{-0.051})}$$

Total Plate Area = $\frac{\{(SCA)\ (FLW)\}}{1000}$ x (% Increase In PM Loading After Lime Inj.)

UncPM Add't = $\frac{250\ (S)\ (Eff\ SO_2) + 17,500\ (\%S)\ (RR)}{H}$

SECTION 4

COSTING METHODOLOGY

This section presents the methodologies used to calculate the capital, operating, and annualized costs of the sorbent injection system.

4.1 CAPITAL COSTS

Capital costs are defined as the total capital investment required to construct and make operational a control system. Table 4-1 presents the individual components of capital cost and the general methodology used for calculating total capital costs. Direct capital costs consist of the basic and auxiliary equipments costs in addition to the installation costs. Indirect costs are those costs not attributable to specific equipment items. Contingencies are included to account for unpredicted events and other unforeseen expenses. Working capital requirements are based on three months of direct annual operating costs.

4.2 OPERATING AND MAINTENANCE (O&M) COSTS

Operating and maintenance costs represent the annual cost necessary to operate and maintain the control system. Table 4-2 lists the individual cost components and the general procedures used in calculating total O&M costs. Direct O&M costs include operating, supervisory, and maintenance labor, utilities, spare parts, waste disposal, and reagent costs. Indirect operating costs include payroll and plant overhead. These overhead costs are calculated based on a percentage of the labor and spare part cost.

Operating and maintenance costs are usually dependent upon the boiler capacity utilization, defined as the actual annual fuel consumption as a percentage of the potential annual fuel consumption at maximum firing rate. However, labor costs do not vary in direct proportion with capacity factor due to shift manpower requirements. It is assumed that the plant will operate on a basis of four six-hour shifts. If the boiler is operating at a capacity

TABLE 4-1. CAPITAL COST COMPONENTS[a]

(1)	Direct Costs	
	Equipment	
+	Installation	(30% of Equipment)
=	Total Direct Costs	
(2)	Indirect Costs	
	Engineering	(10% of total direct costs)
+	Construction and Field Expenses	(10% of total direct costs)
+	Construction Fees	(10% of total direct costs)
+	Start Up Costs	(2% of total direct costs)
+	Performance Costs	(1% of total direct costs)
=	Total Indirect Costs	
(3)	Contingencies = 20% of (Total Indirect + Total Direct Costs)	
(4)	Total Turnkey Cost = Total Indirect Cost + Total Direct Cost + Contingencies	
(5)	Working Capital = 25% of (Total Direct Operating and Maintenance)[b]	
(6)	Total Capital Cost = Total Turnkey + Interest During Construction + Working Capital	

[a]Reference 8.
[b]See Table 4-2.

TABLE 4-2. OPERATING AND MAINTENANCE COST COMPONENTS[a]

(1) Direct Operating Costs

Operating Labor
\+ Supervision
\+ Maintenance Labor
\+ Spare Parts
\+ Electricity
\+ Lime Cost
\+ Waste Disposal
= Total Direct Operating Costs

(2) Indirect Operating Costs (Overhead)

Payroll (30% Operating Labor)
\+ Plant (26% of Operating Labor + Supervision + Maintenance Labor + Spare Parts)

(3) Total Annual Operating and Maintenance Costs = Total Direct + Total Indirect Costs

[a]Reference 8.

factor greater than 0.7, then four manpower shifts are required. At capacity factors less than 0.5, plant operation will require two shifts. In order for reduced labor costs to be reflected at reduced capacity utilization, labor factors are incorporated into the labor cost equations. The relationship between capacity utilization (CF) and labor factors is listed below.

Labor factor = 1	$CF > 0.7$
Labor factor = $0.5 + 2.5\ (CF - 0.5)$	$0.5 \leq CF \leq 0.7$
Labor factor = 0.5	$CF < 0.5$

Table 4-3 lists the recommended unit cost rates used in this analysis.

4.3 ANNUALIZED COSTS

Total annualized costs are the sum of the annual O&M costs and the annualized capital charges. The annualized capital charges include the payoff of the capital investment (capital recovery), interest on working capital, general and administrative costs, taxes, and insurance. Table 4-4 presents the methodology used to calculate the annualized capital charge components. The capital recovery cost is based on the equipment life, real interest rate, and total turnkey cost. For this analysis a 10 percent real interest rate and a 15 year equipment life is assumed for new units. This translates into a capital recovery factor of 13.15 percent. Similarly for retrofit cases a 5 year equipment life is assumed. For retrofit cases the capital recovery factor is 26.38 percent.

TABLE 4-3. UNIT COST RATES[a] RECOMMENDED FOR USE IN CALCULATIONS (JUNE 1985$)

Labor	
Direct Labor	$ 18.77/man hr
Supervision	$ 24.41/man hr
Maintenance Labor	$ 22.85/man hr
Utilities	
Electricity	$ 0.0403/kw hr
Water	$ 0.2379/1000 gallons
Waste Disposal	
Solid Waste	$ 23.80/ton
Raw Material	
Hydrated Lime	$ 75.00/ton
Liquid SO_2	$240.00/ton

[a] Reference 11.

TABLE 4-4. ANNUALIZED COST COMPONENTS[a]

(1) Total Annualized Cost = Annual O&M Costs + Capital Charges

(2) Capital Charges = Capital Recovery + Interest On Working Capital + Miscellaneous (G&A, taxes, and insurance)

(3) Calculation Of Capital Charge Components

A. Capital Recovery = Capital Recovery Factor (CRF) x Total Turnkey Cost

$$CRF = \frac{i\,(1 + i)^n}{(1 + i)^n - 1}$$

i = interest rate

n = number of years of useful life of boiler or control system

Item	n	i	CRF
Control systems	15	10	0.1315
New retrofit	5	10	0.2638

B. Interest On Working Capital = 10% Of Working Capital

C. G&A, Taxes And Insurance = 4% Of Total Turnkey Cost

[a]Reference 8.

SECTION 5

CASE STUDIES

This section presents the results of several case studies. Using the algorithms developed in this report capital, operating and annualized costs are approximated for several model boilers. Costs are examined at two SO_2 removal levels (50 and 70%), several boiler sizes, (100, 250 and, 400 million Btu/hr) and for new and retrofit units.

Specifications for the coal selected for this analysis are presented below:

Heating Value (Btu/lb) - 11,700
Sulfur Content (%) - 1.92
Ash Content (%) - 15.08

The economic premises for this analysis are presented in Table 5-1. Costs were generated for two spreader stoker model boilers (100 and 250 million Btu/hr) and two pulverized coal boilers (250 and 400 million Btu/hr). Table 5-2 and 5-3 present the results of the case studies for new and retrofit boilers respectively.

TABLE 5-1. ECONOMIC PREMISES FOR CASE STUDY

Capital Costs	New	Retrofit
Base Year for Costs	June 1985	June 1985
Equipment Life	15 yr.	5 yr.
Interest Rate	10%	10%
Capital Recovery Factor	0.1315	0.2638
Operating Costs		
Direct Labor Rate ($/manhour)	18.77	18.77
Supervision Labor Rate ($/manhour)	24.41	24.41
Maintenance Labor Rate ($/manhour)	22.85	22.85
Electricity ($/kw-hr)	0.0403	0.0403
Water ($/1000 gallons)	0.2379	0.2379
Solid Waste Disposal ($/ton)	23.80	23.80
Hydrated Lime ($/ton)	75.00	75.00
Liquid SO_2 ($/ton)	240.00	240.00
Capacity Factor	0.6	0.60
PM Emissions Limit (lb/10^6 Btu)	0.05	0.10

TABLE 5-2. FURNACE SORBENT INJECTION COSTS FOR NEW BOILERS

Boiler Type / Size (million Btu/hr)	Capital Costs ($)			Annual Operating Costs ($/yr)			Annualized Costs ($/yr)		
	Furnace Injection System	Particulate Matter Control	Total Capital Cost	Furnace Injection System	Particulate Matter Control	Total Operating Cost	Furnace Injection System	Particulate Matter Control	Total Annualized Cost
Spreader Stoker Boiler									
100 - 50% Removal	384,595	1,138,313	1,522,908	231,460	172,344	403,804	298,758	364,957	658,715
100 - 75% Removal	462,304	1,144,649	1,606,953	380,149	197,686	577,835	453,119	390,933	844,052
250 - 50% Removal	594,165	2,279,192	2,873,357	442,118	373,021	815,139	536,603	758,137	1,294,740
250 - 75% Removal	768,316	2,295,031	3,063,347	813,418	436,376	1,249,794	931,140	823,076	1,754,216
Pulverized Coal Boiler									
250 - 50% Removal	594,165	2,218,192	2,812,357	442,118	367,328	809,446	536,603	742,072	1,278,675
250 - 75% Removal	768,316	2,234,031	3,002,347	813,418	430,688	1,244,101	931,140	807,011	1,738,151
400 - 50% Removal	795,688	3,157,157	3,952,845	652,607	570,479	1,223,086	777,903	1,103,072	1,880,975
400 - 75% Removal	1,061,250	3,182,499	4,243,749	1,246,413	671,847	1,918,260	1,406,648	1,206,974	2,613,622

TABLE 5-3. FURNACE SORBENT INJECTION COSTS FOR RETROFIT BOILERS

Boiler Type / Size (million Btu/hr)	Capital Costs ($)			Annual Operating Costs ($/yr)			Annualized Costs ($/yr)		
	Furnace Injection System	Particulate Matter Control	Total Capital Cost	Furnace Injection System	Particulate Matter Control	Total Operating Cost	Furnace Injection System	Particulate Matter Control	Total Annualized Cost
Spreader Stoker Boiler									
100 - 50% Removal	519,382	1,470,635	1,990,017	287,093	179,424	466,517	419,351	579,734	999,085
100 - 75% Removal	589,467	1,476,032	2,065,499	406,235	201,009	607,244	552,632	601,859	1,154,491
250 - 50% Removal	817,709	2,943,186	3,760,895	581,029	390,719	971,748	782,906	1,190,356	1,973,262
250 - 75% Removal	973,242	2,956,677	3,929,919	878,567	444,681	1,323,248	1,110,356	1,245,667	2,356,023
Pulverized Coal Boiler									
250 - 50% Removal	800,409	5,171,169	5,971,578	577,663	214,057	791,720	792,795	1,774,464	2,567,259
250 - 75% Removal	945,056	6,376,607	7,321,663	873,136	310,599	1,183,735	1,117,168	2,232,371	3,349,539
400 - 50% Removal	1,074,967	6,277,127	7,352,094	869,365	330,931	1,200,296	1,153,079	2,221,439	3,374,518
400 - 75% Removal	1,298,178	7,823,546	9,116,724	1,341,907	483,185	1,825,092	1,667,855	2,835,830	4,503,685

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Appendix A

Furnace Lime Injection Costs for New Industrial Boilers

```
A10: [W25] 'Input Data
D10: 'Cost Summary
A12: U [W25] 'Q (MMBTU/hr)
B12: U [W11] 1200
D12: 'New - LIMB, FF
A13: U [W25] 'Blr Type (Sprd=1, Plvr=2)
B13: U [W11] 2
D13: 'Lime Injection System Costs
A14: U [W25] 'Cf
B14: U [W11] 0.6
D14: 'Capital
E14: (C0) [W13] +B71
A15: U [W25] 'S (%)
B15: U [W11] 3.23
D15: 'Tot O&M
E15: (C0) [W13] +E64
A16: U [W25] 'A (%)
B16: U [W11] 12
D16: 'Tot Ann
E16: (C0) [W13] +E71
A17: U [W25] 'H (BTU/lb)
B17: U [W11] 11700
A18: U [W25] 'Eff SO2 (%)
B18: (F0) U [W11] 70
D18: 'PM Control Fabric Filter Costs
A19: U [W25] 'Ctrpm (lb/MMBTU)
B19: U [W11] 0.1
D19: 'Capital
E19: (C0) [W13] +H63
A20: U [W25] 'DLR ($/manhr)
B20: U [W11] 18.77
D20: 'Tot O&M
E20: (C0) [W13] +K65
A21: U [W25] 'SLR ($/manhr)
B21: U [W11] 24.41
D21: 'Tot Ann
E21: (C0) [W13] +K71
A22: U [W25] 'MLR($/manhr)
B22: U [W11] 22.85
A23: U [W25] 'Elec ($/KW)
B23: U [W11] 0.0403
D23: 'Total System Costs
A24: U [W25] 'Lime Rate ($/ton)
B24: U [W11] 47
D24: 'Capital
```

```
E24: (C0) [W13] +E14+E19
A25: U [W25] 'SWR ($/ton)
B25: U [W11] 23.8
D25: 'Tot O&M
E25: (C0) [W13] +E15+E20
A26: U [W25] 'WTR ($/1000 gal)
B26: U [W11] 0.2379
D26: 'Tot Ann
E26: (C0) [W13] +E16+E21
A27: U [W25] 'SO2R ($/ton)
B27: U [W11] 240
A33: [W25] 'Data calculated from inputs
A34: [W25] 'used in cost algorithms.
A36: [W25] 'Flw (acfm)
B36: (F0) [W11] @IF(B13=1,@EXP(0.0000814*B17)*(1660000*B12/B17),@EXP(8.03*10^-5*B
A37: [W25] 'Unc PM add't
B37: (F2) [W11] (250*B18*B15+17500*B15*B41)/B17
A38: [W25] 'Unc PM Coal
B38: (F2) [W11] 30000/B17
A39: [W25] 'Uncpm tot
B39: (F2) [W11] +B37+B38
A40: [W25] 'Eff PM
B40: (F2) [W11] (B39-B19)/B39*100
A41: [W25] 'RR (mol Ca/mol S)
B41: (F2) [W11] 2.7*(@LN(0.956/(1-B18/100)))
A42: [W25] 'Labor Fact.
B42: [W11] 0.5+(2.5*(B14-0.5))
A43: [W25] '% Incr. in PM
B43: (F2) [W11] (B37/B38)*100
A44: [W25] 'LFR
B44: (F2) [W11] 24266*B12*B15*B41/B17
A49: [W25] 'Detailed Costs
A50: [W25] '(The costs presented below are for a new unit.
A51: [W25] '  For retrofit units multiply the new costs by 1.3.)
A53: [W25] 'New Lime Inj. Capital Costs
D53: 'New Lime Inj O&M Costs
G53: [W7] 'PM Control - FF Capital Costs
J53: 'PM control -FF O&M
A55: [W25] 'stor silo
B55: (C0) [W11] 53.4*B44^0.82
D55: 'dir lab
E55: (C0) [W13] 2600*B20*B42
G55: [W7] 'equip
H55: (C0) [W13] 12.3578*(B36^0.966)
J55: 'dir lab
K55: (C0) [W11] (844.426+8.8186*B12)*B20*B42
A56: [W25] 'feed bin
B56: (C0) [W11] 265.5*B44^0.6145
D56: 'sup lab
E56: (C0) [W13] 390*B21*B42
```

```
G56: [W7] 'install
H56: (C0) [W13] -2232293+249721*@LN(B36)
J56: 'sup lab
K56: (C0) [W11] 0
A57: [W25] 'grav feed
B57: (C0) [W11] 0.8667*B44+27879
D57: 'mant lab
E57: (C0) [W13] 650*B22*B42
G57: [W7] 'ind
H57: (C0) [W13] 37.03*(B36^0.821)
J57: 'mant lab
K57: (C0) [W11] (1014.35+0.0072*(B12^2))*B22*B42
A58: [W25] 'pneu conv
B58: (C0) [W11] 6*9614*(@EXP((2.21*10^-5)*B44))
D58: 'sp parts
E58: (C0) [W13] 0.02*B67
J58: 'sp parts
K58: (C0) [W11] 2*0.432*(B36^0.997)
A59: [W25] 'inj ports
B59: (C0) [W11] 0.25*B58
D59: 'elec
E59: (C0) [W13] 5*8760*B23*B14*(0.0012*B44+5.75)
G59: [W7] 'TDI
H59: (C0) [W13] @SUM(H55..H57)
J59: 'elec
K59: (C0) [W11] 47.8*B23*B36^0.953*B14
A60: [W25] 'sootblwr
B60: (C0) [W11] 73*B12
D60: 'lime
E60: (C0) [W13] +B24*8760*B44*B14/2000
G60: [W7] 'cont
H60: (C0) [W13] 0.2*H59
J60: 'sol wste
K60: (C0) [W11] 4.38*B14*B12*B25*(B39-B19)
A61: [W25] 'tube resp
B61: (C0) [W11] 254*B12
G61: [W7] 'TK
H61: (C0) [W13] +H59+H60
J61: 'lime sav
K61: (C0) [W11] -0.438*B44*B14*B24
D62: 'TDOM
E62: (C0) [W13] @SUM(E55..E60)
G62: [W7] 'wc
H62: (C0) [W13] 0.25*K63
A63: [W25] 'total equip
B63: (C0) [W11] @SUM(B55..B61)
D63: 'ind O&M
E63: (C0) [W13] 0.3*E55+0.26*(@SUM(E55..E58))
G63: [W7] 'Tot cap
H63: (C0) [W13] +H61+H62
```

```
J63: 'TDOM
K63: (C0) [W11] @SUM(K55..K61)
A64: [W25] 'install
B64: (C0) [W11] 0.3*B63
D64: 'Tot O&M
E64: (C0) [W13] +E62+E63
J64: 'ind O&M
K64: (C0) [W11] 0.3*K55+0.26*@SUM(K55..K58)
A65: [W25] 'tot dir
B65: (C0) [W11] +B63+B64
J65: 'Tot O&M
K65: (C0) [W11] +K63+K64
A66: [W25] 'ind
B66: (C0) [W11] 0.33*B65
A67: [W25] 'TDI
B67: (C0) [W11] +B65+B66
D67: 'Annualized costs
J67: 'Annualized PM costs
A68: [W25] 'cont
B68: (C0) [W11] 0.2*B67
D68: 'cr
E68: (C0) [W13] +B69*0.1315
J68: 'cr
K68: (C0) [W11] 0.1315*H61
A69: [W25] 'TK
B69: (C0) [W11] +B67+B68
D69: 'int wc
E69: (C0) [W13] +B70*0.1
J69: 'int wc
K69: (C0) [W11] 0.1*H62
A70: [W25] 'wc
B70: (C0) [W11] 0.25*E62
D70: 'misc
E70: (C0) [W13] +B69*0.04
J70: 'misc
K70: (C0) [W11] 0.04*H61
A71: [W25] 'tot cap
B71: (C0) [W11] +B69+B70
D71: 'tot ann
E71: (C0) [W13] +E68+E69+E70+E64
J71: 'tot ann
K71: (C0) [W11] @SUM(K68..K70)+K65
```

Appendix B

Furnace Lime Injection Costs for Retrofit Boilers firing 250 million BTU/hr or more

```
A10: [W32] 'Input Data
D10: 'Cost Summary
D12: 'Retrofit - LIMB, ESP
A13: [W32] 'Q (MMBTU/hr)
B13: U [W11] 250
D13: 'Lime Injection System Costs
A14: [W32] 'Blr Type (Sprd=1, Plvr=2)
B14: U [W11] 1
D14: 'Capital
E14: (C0) [W14] 1.3*B65+B66
A15: [W32] 'Wet or Dry Bottom (Wet=1, Dry=2)
B15: U [W11] 2
D15: 'Tot O&M
E15: (C0) [W14] +E60
A16: [W32] 'Cf
B16: U [W11] 0.6
D16: 'Tot Ann
E16: (C0) [W14] 1.3*(E64+E66)+E65+E15
A17: [W32] 'S (%)
B17: U [W11] 1.92
A18: [W32] 'A (%)
B18: U [W11] 15.08
D18: 'PM Control Electrostatic Precipitator Costs
A19: [W32] 'H (lb/BTU)
B19: U [W11] 11700
D19: 'Capital
E19: (C0) [W14] +H59
A20: [W32] 'Eff SO2 (%)
B20: (F0) U [W11] 70
D20: 'Tot O&M
E20: (C0) [W14] +K62
A21: [W32] 'Ctr PM (lb/MMBTU)
B21: U [W11] 0.1
D21: 'Tot Ann
E21: (C0) [W14] +K68
A22: [W32] 'DLR ($/manhr)
B22: U [W11] 18.77
A23: [W32] 'SLR ($/manhr)
B23: U [W11] 24.41
D23: 'Total System Costs
A24: [W32] 'MLR ($/manhr)
B24: U [W11] 22.85
D24: 'Capital
E24: (C0) [W14] +E14+E19
A25: [W32] 'Elec ($/KW)
B25: U [W11] 0.0403
```

```
D25: 'Tot O&M
E25: (C0) [W14] +E15+E20
A26: [W32] 'Lime Rate ($/ton)
B26: U [W11] 75
D26: 'Tot Ann
E26: (C0) [W14] +E16+E21
A27: [W32] 'SWR ($/ton)
B27: U [W11] 23.8
A28: [W32] 'WTR ($/1000 gal)
B28: U [W11] 0.2379
A29: [W32] 'SO2R ($/ton)
B29: U [W11] 240
A31: [W32] 'Data calculated from inputs
A32: [W32] 'used in cost algorithms
A33: [W32] 'Flw (acfm)
B33: (F0) [W11] @IF(B14=1,@EXP(0.0000814*B19)*(1660000*B13/B19),@EXP(8.03*10^-5*B
A34: [W32] 'Unc PM add't (lb/MMBtu)
B34: (F2) [W11] (250*B17*B20+17500*B17*B38)/B19
A35: [W32] 'Unc PM Coal (lb/MMBtu)
B35: (F2) [W11] @IF(B14=1,30000/B19,@IF(B15=1,3500*B18/B19,5000*B18/B19))
A36: [W32] 'Uncpm tot (lb/MMBtu)
B36: (F2) [W11] +B34+B35
A37: [W32] 'Eff PM
B37: (F3) [W11] (B36-B21)/B36*100
A38: [W32] 'RR (mol Ca/mol S)
B38: (F2) [W11] 0.06*B20-0.55
A39: [W32] 'Labor Factor
B39: [W11] @IF(B16>0.7,1,@IF(B16<0.5,0.5,0.5+2.5*(B16-0.5)))
A40: [W32] '% Incr. in PM
B40: (F2) [W11] (B34/B35)*100
A41: [W32] 'SCA
B41: (F2) [W11] 383*B17^(-11.256*B37^-0.745)*(100-B37)^(-0.366*B17^-0.051)
A42: [W32] 'TPA
B42: (F0) [W11] (+B41*B33/1000)*B40/100
A43: [W32] 'Sorbent Feed Rate (lb/hr)
B43: (F0) [W11] 24266*B13*B17*B38/B19
A46: [W32] 'Detailed Costs
A47: [W32] '(The LIMB capital costs below are for new units.
A48: [W32] '   For retrofit multiply the new costs by 1.3.)
A50: [W32] 'New lime inj. cap
D50: 'New lime inj O&M
G50: [W11] 'PM control - ESP cap
J50: 'PM control - ESP O&M
A51: [W32] 'stor silo
B51: (C0) [W11] 53.4*B43^0.82
D51: 'dir lab
E51: (C0) [W14] 2600*B22*B39
G51: [W11] 'equip
H51: (C0) [W12] 3475*(B42^0.52)+216913*(B13^0.15)
J51: 'dir lab
```

```
K51: (C0) [W12] 0
A52: [W32] 'feed bin
B52: (C0) [W11] 265.5*B43^0.6145
D52: 'sup lab
E52: (C0) [W14] 390*B23*B39
G52: [W11] 'install
H52: (C0) [W12] +H51*1.1
J52: 'sup lab
K52: (C0) [W12] 0
A53: [W32] 'grav feed
B53: (C0) [W11] 0.8667*B44+27879
D53: 'mant lab
E53: (C0) [W14] 650*B24*B39
G53: [W11] 'ind
H53: (C0) [W12] 0.334*(H51+H52)
J53: 'mant lab
K53: (C0) [W12] 0
A54: [W32] 'pneu conv
B54: (C0) [W11] 6*9614*(@EXP((2.21*10^-5)*B44))
D54: 'sp parts
E54: (C0) [W14] 0.02*B63
J54: 'sp parts
K54: (C0) [W12] 0.00552*(@SUM(H51..H53))
A55: [W32] 'inj ports
B55: (C0) [W11] 0.25*B54
D55: 'elec
E55: (C0) [W14] 5*8760*B25*B16*(0.0012*B44+5.75)
G55: [W11] 'TDI
H55: (C0) [W12] @SUM(H51..H53)
J55: 'elec
K55: (C0) [W12] 26.68*B16*B25*B43
A56: [W32] 'sootblwr
B56: (C0) [W11] 73*B13
D56: 'lime
E56: (C0) [W14] +B26*8760*B43*B16/2000
G56: [W11] 'cont
H56: (C0) [W12] 0.2*H55
J56: 'sol wste
K56: (C0) [W12] 4.38*B16*B13*B27*B34
A57: [W32] 'tube resp
B57: (C0) [W11] 254*B13
G57: [W11] 'TK
H57: (C0) [W12] +H55+H56
J57: 'liq so2
K57: (C0) [W12] 2.48*10^-3*B33*B16*B29
D58: 'TDOM
E58: (C0) [W14] @SUM(E51..E56)
G58: [W11] 'wc
H58: (C0) [W12] 0.25*K60
J58: 'wtr
```

```
K58: (C0) [W12] 28.03*B13*B16*B28*B34
A59: [W32] 'total equip
B59: (C0) [W11] @SUM(B51..B57)
D59: 'ind O&M
E59: (C0) [W14] 0.3*E51+0.26*(@SUM(E51..E54))
G59: [W11] 'Tot cap
H59: (C0) [W12] +H57+H58
A60: [W32] 'install
B60: (C0) [W11] 0.3*B59
D60: 'Tot O&M
E60: (C0) [W14] +E58+E59
J60: 'TDOM
K60: (C0) [W12] @SUM(K51..K58)
A61: [W32] 'tot dir
B61: (C0) [W11] +B59+B60
J61: 'ind O&M
K61: (C0) [W12] 0.3*K51+0.26*@SUM(K51..K54)
A62: [W32] 'ind
B62: (C0) [W11] 0.33*B61
J62: 'Tot O&M
K62: (C0) [W12] +K60+K61
A63: [W32] 'TDI
B63: (C0) [W11] +B61+B62
D63: 'Annualized costs
A64: [W32] 'cont
B64: (C0) [W11] 0.2*B63
D64: 'cr
E64: (C0) [W14] +B65*0.2638
J64: 'Annualized PM costs
A65: [W32] 'TK
B65: (C0) [W11] +B63+B64
D65: 'int wc
E65: (C0) [W14] +B66*0.1
J65: 'cr
K65: (C0) [W12] 0.2638*H57
A66: [W32] 'wc
B66: (C0) [W11] 0.25*E58
D66: 'misc
E66: (C0) [W14] +B65*0.04
J66: 'int wc
K66: (C0) [W12] 0.1*H58
A67: [W32] 'tot cap
B67: (C0) [W11] +B65+B66
D67: 'tot ann
E67: (C0) [W14] +E64+E65+E66+E60
J67: 'misc
K67: (C0) [W12] 0.04*H57
J68: 'tot ann
K68: (C0) [W12] @SUM(K65..K67)+K62
```

Appendix C

Furnace Lime Injection Costs for Retrofit Boilers firing less than 250 million BTU/hr

```
A10: [W32] "Input Data
D10: 'Cost Summary
A12: U [W32] 'Q (MMBTU/hr)
B12: U [W11] 100
D12: 'Retrofit - LIMB, FF
A13: U [W32] 'Blr Type (Sprd=1, Plvr=2)
B13: U [W11] 1
D13: 'Lime Injection System Costs
A14: U [W32] 'Wet or Dry Bottom (Wet=1, Dry=2)
B14: U [W11] 2
D14: 'Capital
E14: (C0) [W13] 1.3*B69+B70
A15: U [W32] 'Cf
B15: U [W11] 0.6
D15: 'Tot O&M
E15: (C0) [W13] +E64
A16: U [W32] 'S (%)
B16: U [W11] 1.92
D16: 'Tot Ann
E16: (C0) [W13] 1.3*(E68+E70)+E69+E15
A17: U [W32] 'A (%)
B17: U [W11] 15.08
A18: U [W32] 'H (BTU/lb)
B18: U [W11] 11700
D18: 'PM Control Fabric Filter Costs
A19: U [W32] 'Eff SO2 (%)
B19: (F0) U [W11] 70
D19: 'Capital
E19: (C0) [W13] +H63
A20: U [W32] 'Ctrpm (lb/MMBTU)
B20: U [W11] 0.05
D20: 'Tot O&M
E20: (C0) [W13] +K65
A21: U [W32] 'DLR ($/manhr)
B21: U [W11] 18.77
D21: 'Tot Ann
E21: (C0) [W13] +K71
A22: U [W32] 'SLR ($/manhr)
B22: U [W11] 24.41
A23: U [W32] 'MLR($/manhr)
B23: U [W11] 22.85
D23: 'Total System Costs
A24: U [W32] 'Elec ($/KW)
B24: U [W11] 0.0403
D24: 'Capital
E24: (C0) [W13] +E14+E19
A25: U [W32] 'Lime Rate ($/ton)
B25: U [W11] 75
D25: 'Tot O&M
```

```
E25: (C0) [W13] +E15+E20
A26: U [W32] 'SWR ($/ton)
B26: U [W11] 23.8
D26: 'Tot Ann
E26: (C0) [W13] +E16+E21
A27: U [W32] 'WTR ($/1000 gal)
B27: U [W11] 0.2379
A28: U [W32] 'SO2R ($/ton)
B28: U [W11] 240
A33: [W32] 'Data calculated from inputs
A34: [W32] 'used in cost algorithms.
A36: [W32] 'Flw (acfm)
B36: (F0) [W11] @IF(B13=1,@EXP(0.0000814*B18)*(1660000*B12/B18),@EXP(8.03*10^-5*B
A37: [W32] 'Unc PM add't (lb/MMBtu)
B37: (F2) [W11] (250*B19*B16+17500*B16*B41)/B18
A38: [W32] 'Unc PM Coal (lb/MMBtu)
B38: (F2) [W11] @IF(B13=1,30000/B18,@IF(B14=1,3500*B17/B18,5000*B17/B18))
A39: [W32] 'Uncpm tot (lb/MMBtu)
B39: (F2) [W11] +B37+B38
A40: [W32] 'Eff PM
B40: (F3) [W11] (B39-B20)/B39*100
A41: [W32] 'RR (mol Ca/mol S)
B41: (F2) [W11] 0.06*B19-0.55
A42: [W32] 'Labor Factor
B42: [W11] @IF(B15>0.7,1,@IF(B15<0.5,0.5,0.5+2.5*(B15-0.5)))
A43: [W32] '% Incr. in PM
B43: (F2) [W11] (B37/B38)*100
A44: [W32] 'LFR
B44: (F2) [W11] 24266*B12*B16*B41/B18
A49: [W32] 'Detailed Costs
A50: [W32] '(The costs presented below are for a new unit.
A51: [W32] '  For retrofit units multiply the new costs by 1.3.)
A53: [W32] 'New Lime Inj. Capital Costs
D53: 'New Lime Inj O&M Costs
G53: [W7] 'PM Control - FF Capital Costs
J53: 'PM control -FF O&M
A55: [W32] 'stor silo
B55: (C0) [W11] 53.4*B44^0.82
D55: 'dir lab
E55: (C0) [W13] 2600*B21*B42
G55: [W7] 'equip
H55: (C0) [W13] 12.3578*(B36^0.966)*1.3
J55: 'dir lab
K55: (C0) [W13] (844.426+8.8186*B12)*B21*B42
A56: [W32] 'feed bin
B56: (C0) [W11] 265.5*B44^0.6145
D56: 'sup lab
E56: (C0) [W13] 390*B22*B42
G56: [W7] 'install
H56: (C0) [W13] (-2232293+249721*@LN(B36))*1.3
J56: 'sup lab
K56: (C0) [W13] 0
A57: [W32] 'grav feed
B57: (C0) [W11] 0.8667*B44+27879
D57: 'mant lab
E57: (C0) [W13] 650*B23*B42
G57: [W7] 'ind
H57: (C0) [W13] 37.03*(B36^0.821)*1.3
J57: 'mant lab
K57: (C0) [W13] (1014.35+0.0072*(B12^2))*B23*B42
```

```
A58: [W32] 'pneu conv
B58: (C0) [W11] 6*9614*(@EXP((2.21*10^-5)*B44))
D58: 'sp parts
E58: (C0) [W13] 0.02*B67
J58: 'sp parts
K58: (C0) [W13] 2*0.432*(B36^0.997)
A59: [W32] 'inj ports
B59: (C0) [W11] 0.25*B58
D59: 'elec
E59: (C0) [W13] 5*8760*B24*B15*(0.0012*B44+5.75)
G59: [W7] 'TDI
H59: (C0) [W13] @SUM(H55..H57)
J59: 'elec
K59: (C0) [W13] 47.8*B24*B36^0.953*B15
A60: [W32] 'sootblwr
B60: (C0) [W11] 73*B12
D60: 'lime
E60: (C0) [W13] +B25*8760*B44*B15/2000
G60: [W7] 'cont
H60: (C0) [W13] 0.2*H59
J60: 'sol wste
K60: (C0) [W13] 4.38*B15*B12*B26*(B39-B20)
A61: [W32] 'tube resp
B61: (C0) [W11] 254*B12
G61: [W7] 'TK
H61: (C0) [W13] +H59+H60
J61: 'lime sav
K61: (C0) [W13] -0.438*B44*B15*B25
D62: 'TDOM
E62: (C0) [W13] @SUM(E55..E60)
G62: [W7] 'wc
H62: (C0) [W13] 0.25*K63
A63: [W32] 'total equip
B63: (C0) [W11] @SUM(B55..B61)
D63: 'ind O&M
E63: (C0) [W13] 0.3*E55+0.26*(@SUM(E55..E58))
G63: [W7] 'Tot cap
H63: (C0) [W13] +H61+H62
J63: 'TDOM
K63: (C0) [W13] @SUM(K55..K61)
A64: [W32] 'install
B64: (C0) [W11] 0.3*B63
D64: 'Tot O&M
E64: (C0) [W13] +E62+E63
J64: 'ind O&M
K64: (C0) [W13] 0.3*K55+0.26*@SUM(K55..K58)
A65: [W32] 'tot dir
B65: (C0) [W11] +B63+B64
J65: 'Tot O&M
K65: (C0) [W13] +K63+K64
A66: [W32] 'ind
B66: (C0) [W11] 0.33*B65
A67: [W32] 'TDI
B67: (C0) [W11] +B65+B66
D67: 'Annualized costs
J67: 'Annualized PM costs
A68: [W32] 'cont
B68: (C0) [W11] 0.2*B67
D68: 'cr
E68: (C0) [W13] +B69*0.2368
```

```
J68: 'cr
K68: (C0) [W13] 0.2368*H61
A69: [W32] 'TK
B69: (C0) [W11] +B67+B68
D69: 'int wc
E69: (C0) [W13] +B70*0.1
J69: 'int wc
K69: (C0) [W13] 0.1*H62
A70: [W32] 'wc
B70: (C0) [W11] 0.25*E62
D70: 'misc
E70: (C0) [W13] +B69*0.04
J70: 'misc
K70: (C0) [W13] 0.04*H61
A71: [W32] 'tot cap
B71: (C0) [W11] +B69+B70
D71: 'tot ann
E71: (C0) [W13] +E68+E69+E70+E64
J71: 'tot ann
K71: (C0) [W13] @SUM(K68..K70)+K65
```